The Study of Evaporation of Multicomponent Drops Using an Acousto-Electric Levitator

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Abstract: The evaporation of isolated drops and drop arrays of multicomponent liquid is investigated using a novel acousto-electric levitator. By simultaneous levitation and charging of the drops, we can form 2-D drop arrays with drop diameters varying from 0.2 to 1 mm. Also by controlling both the acoustic and electric field intensities, we can create arrays with different drop sizes and drop spacings. This allows us to study the effect of the interference among drops in an evaporating dense spray. Mixtures of different liquids such as alkanes (heptane, dodecane and hexadecane) are studied. The evaporation rates of those mixtures with different molar ratios of components and different numbers of drops in an array are measured. The drop size and spacing are carefully controlled and varied. A video camera is used to record the drop size change with time, and the diameters of drops are calculated from the pictures. The results are compared with a theoretical analysis based on the diffusion-controlled evaporation model. [Work supported by NASA through JPL grant 958722.]

INTRODUCTION

In spray combustion, evaporation is the first step in the sequence of all combustion events. The evaporation rate of fuel drops is an important factor in determining the flame behavior and fuel efficiency. In practice, fuels are the mixtures of many chemical compounds of different volatilities. Although the evaporation of an isolated single-component drop in a stagnant, unbounded atmosphere has been well characterized (1), that of multi-component drops and drop arrays is more complicated and needs to be further studied. Some different theoretical models have been developed for multicomponent drop and drop array evaporation, but very limited experimental data exists. By suspending an isolated fuel drop or a 2-D drop array in our acousto-electric levitator, we can study the evaporation of multicomponent drops and compare our results with theory.

THEORY

The evaporation of an isolated single-component drop obeys the $d^2$-law, which states that the square of the drop diameter decreases linearly with time as gasification proceeds. The $d^2$-law is derived from the mass and energy conservation laws. These two conservation laws can also be used for multicomponent fuels by writing down the equations for each species separately. If Raoult’s law is applied, the molar flux of the $i$th species in an isolated multicomponent drop is

$$J_i = \gamma_i D_i \rho^0 T \chi_i / a RT,$$ (1)

where $D_i$ is the diffusion coefficient of vapor $i$, $\rho^0$ is the vapor pressure at surface temperature $T$, $\chi_i$ is the molar fraction of the $i$th species in the drop, $a$ and $R$ are the radius of the drop and the gas constant respectively. $\gamma_i$ is the activity coefficient of the $i$th species, which depends on the fraction of the $i$th species in the drop. The change of the square of the drop diameter can be a function of the fraction of each species but does not have an explicit form. The activity coefficients should be continuously updated with time. The above is a simplified diffusion-controlled model. Due to the interaction among drops, the flow field in an array is quite complicated. Some methods such as the Method of Images, the Point Source Method and the Continuum Method are now used to deal with multi-drop evaporation (2). The Method of Images is suitable for arrays of fewer than 20 drops, but the Continuum Method is suitable for clouds. Numerical simulation is often applied in these studies.

EXPERIMENTAL APPARATUS AND PROCEDURE

Figure 1 shows the experimental apparatus developed from an acoustic levitator, which had been successfully used to study drop dynamics (3). A standing acoustic wave around 28 KHz is generated in the gap between the transducer and the reflector. The acoustic field is monitored by a PVDF film on the reflector. Due to the vertical acoustic radiation force, drops are levitated a little below the acoustic pressure node. In order to form drop arrays, a high DC voltage is applied between the gap. After liquid is injected on the vibration plate, very small initial drops are generated on the surface via an ultrasonic atomization technique. These drops are charged and fly into the gap. Because of the acoustic radiation force, small seed drops coalesce to form an array of large drops below the pressure
node. Drops are separated by coulombic forces but held together by the lateral acoustic radiation force. Shown in Figure 2 is a typical levitated 2-D drop array. The levitation device allows us to control the drop sizes, the drop spacing, and the number of drops, by changing both the acoustic field intensity and the DC voltage (4). For example, increasing the acoustic intensity will decrease the total number of drops but increase the drop size. A CCD camera records the change of drop size from the top of the test chamber through a glass window. A frame grabber card captures the video into image sequences. The image sequences are analyzed by special software that can track each drop, automatically detect the drop edges, and calculate the drop sizes.

Figure 1. Experimental Apparatus

Figure 2. A 2-D Drop Array

Our work focuses on the evaporation of multicomponent organic drops. Mixtures of different molar percentages of alkanes (heptane, dodecane and hexadecane) are used in the measurement.

INITIAL RESULTS

Figure 3 shows the results of the evaporation of pure heptane and pure dodecane isolated drops. Heptane, whose vapor pressure $p^\circ$ at room temperature is 6.1 KPa, is a much more volatile material than dodecane, whose $p^\circ$ is only 0.1 KPa. Their evaporations obey the $d^2$-law. The experimental results for a mixture composed of 70\% of heptane and 30\% of dodecane in mol units is shown in Figure 4. This result is compared with the numerical calculation based on the diffusion-controlled model for binary components with fixed activity coefficients. Agreement is seen to be good.

Figure 3. Evaporation of pure heptane and pure dodecane isolated drops

Figure 4. Evaporation of an isolated drop of heptane and dodecane mixture

REFERENCE